Fixed-Mobile Convergence: Using Unlicensed DECT Frequencies in UMTS Femtocell Services Deployment

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Abstract. In this paper, we explore the possibility of using unlicensed DECT frequency bands to deploy UMTS Femtocells in the user homes. This solution gives the possibility for ISP providers to enter the mobile market without being forced to pay for the use of the frequencies licensed to the incumbent operators. This study starts from the analysis of the legislation on the use of the DECT and UMTS frequency bands for short-range voice communications and defines the changes required on the current UMTS handsets and Femtocells for the use of the DECT frequencies. Changes on both superheterodyne and homodyne transceivers have been investigated, as well as the modifications on the procedure the handset has to follow to select the DECT bands. The narrowness of the DECT bandwidth doesn't allow for having a safe guard band between the Uplink and Downlink channels, as it is for the current UMTS system. We then conducted simulations to evaluate the impact of this feature on the system performance.

Keywords: DECT, UMTS, fixe-mobile convergence.

1 Introduction

Motivated by the extraordinary and increasing economic value of the mobile services market, fixed ISPs (Internet Service Provides) are struggling to find the easiest and cheapest way to take a major role in it. However, the possible solutions are all restricted by the use of the access network frequencies (in WCDMA, GSM and UMTS networks), which are already completely assigned to the incumbent mobile operators [1]. Waiting for the regulating bodies to free bands that are now assigned to other uses, such as the digital television VHF frequencies that can be released when switching to the digital system, the ISPs have no way to enter the market other than paying for the use of the radio resources licensed to the incumbent operators [1]. Accordingly, they become MVNO (Mobile Virtual Network Operators), relying on the radio spectrum and infrastructure of the MVO (Mobile Virtual Operator).

In this scenario, the Femtocell technologies takes up a key role. A Femtocell is a small cellular base station, typically designed for use in a home or small business premise, which connects to the service provider network via broadband

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(such as DSL or cable), supporting a few active mobile phones in a residential and enterprise settings [3]. This brings to the achievement of the Fixed-Mobile Convergence (FMC), which consists in bringing (almost) the same services over fixed and mobile connections. For a mobile operator, the attractions of a Femtocell are improvements to both coverage and capacity, especially indoors. From the fixed ISP providers, the Femtocell is a way of exploiting the widespread of their broadband networks and their *presence* in private and business customer premises. These are advantages that the ISP can deal with the mobile operator, so that he can exchange the use of the licensed frequencies with the routing and transport of the mobile operator customers calls.

Another way to implement a similar scenario is the mobile connectivity at home making use of the WiFi technology and using a dual-mode handset. This would work with existing unlicensed spectrum home/enterprise wireless access points, while a Femtocell-based deployment would work with existing handsets but requires installation of a new access point that uses licensed spectrum. The main advantages are that WiFi makes use of unlicensed spectrum and that the WiFi radio interface is going to be available on most of the current smartphone available on the market. The main disadvantage is that the 2.4 GHz ISM band is more and more crowded causing annoying interferences that don't allow for guarantying robust communications. Additionally, using the WiFi radio for dialing voice communication requires tricky operations to be carried out by the end-user, who is instead used to push a few clear buttons when dialing mobile calls [2].

From these basic considerations, it comes up that the entrance of ISPs in the mobile market is quite intricate and that the most viable and the easiest solution doesn't exist or hasn't been discovered yet. Specifically, we believe that the best solution depends on the ISP characteristics (mainly in terms of DSL coverage and customers profiles), business model, target users, existing competitors, additional services to be provided and other important factors.

Following this view, in this paper we explore an additional option, which relies on using the DECT (Digital Enhanced Cordless Telecommunication) unlicensed frequency band to deploy UMTS Femtocell in the user homes. The idea is quite straightforward and consists in keeping the UMTS terminal handset almost unchanged apart from the physical layer, which should be changed in order to transmit in the DECT band. This is the band 1880 –1900 MHz in Europe and in many other countries outside, and 1920 – 1930 MHz in USA [7]. This study starts from the analysis of the legislation on the use of the DECT and UMTS frequency band for short-range voice communications and investigates on the changes required on the current UMTS handset for the use of the DECT frequencies. Changes on both superheterodyne and homodyne handsets have been investigated as well as the modifications on the procedure the handset has to follow to make use of the DECT bands. The proposed solution has the following two advantages: the use of unlicensed frequency bands and the provisioning of mobile services to the end-user with the same traditional mobile user experience, handover included. The narrowness of the DECT bandwidth doesn't allow for having a safe guard band between the Uplink and Downlink channels, as it is for the UMTS system. We then conducted simulations to evaluate the impact of this feature on the system performance.

The paper is organized as follows. The second section provides the background information about the UMTS system, the Femtocell technologies and the mobile communications frequency bands. Section three presents the results of our study and proposes the changes that need to be introduced with respect to standard UMTS platforms. The following section provides preliminary results on the performance analysis of the proposed system, whereas the last section draws final conclusion.

2 Background

2.1 UMTS System

UMTS has been specified by 3GPP, and is part of ITU's IMT-2000 family of the third generation standards. The major innovation of UMTS is Code Division Multiple Access (CDMA): each transmission is assigned a unique pseudo-noise sequence of pulses, named chips, whose duration is much smaller than information bit's duration; multiplying each bit by such a sequence spreads the signal energy over a wider bandwidth. Spreading codes are orthogonal to each other, and thus signals from different transmission channels are uncorrelated. There exist two kinds of spreading codes: channelization codes, which discriminate between different physical channels, and spreading codes, which discriminate between different transmitters, whether they are mobile terminals or Node Bs.

UMTS architecture is composed of three principal elements interconnected to each other:

- Core Network (CN);
- Universal Terrestrial Radio Access Network (UTRAN), in its turn composed by Radio Network Control (RNC), connected to CN, and Node B, connected to UE;
- User Equipment (UE).

A fundamental part of the UE is the Universal Subscriber Identity Module (USIM), which contains data about the user and his service profile, and the network. These data are stored in Elementary Files (EFs), which are organized in a file system structure. EFs are particularly important when the UE is trying to access the network, such as when it is turned on, or when it is trying to access a different Public Land Mobile Network (PLMN[1]), whether it is a periodic request or it comes from the user.

When it is turned on, the mobile phone performs a cell selection, which consists in searching a suitable cell to camp on. In order to make the cell search

[1] PLMN is a network that is established and operated by a service provider or administrator. It is identified by the Mobile Country Code (MCC) and the Mobile Network Code (MNC).

faster, cell information — like carrier frequency and scrambling code — stored in some EFs can be used; otherwise, a full scan over all carrier frequencies is performed, until a suitable cell is found. When the UE finds a strong enough primary synchronization signal, which is a universally known code, it acquires time slot synchronization from it. Afterwards, the UE acquires frame synchronization, and finally it can determine the scrambling code. At this point, the synchronization with the network can be considered concluded, and the mobile terminal can detect the P-CCPCH. It carries the logical channel BCH, which broadcasts the system information through the RRC protocol. Some of the System Information Blocks (SIBs) contain, among others, Information Elements (IEs) about what PLMN the cell and the neighbouring cells belong to. For example, through SIBs the Node B can notify to the mobile phone the carrier frequency of that or a neighbouring cell, either for Downlink or, optionally, for Uplink: the IE Frequency Info defines (or redefines) what channels the terminal should use, reporting the corresponding UMTS Absolute Radio Frequency Channel Numbers (UARFCNs).

Once the device receives the SIBs, it selects the cell belonging to the PLMN corresponding to the one indicated as the Home PLMN in the EF_{HPLM}, or else, if there is a priority ordered list of Equivalent HPLMN in the EF_{EHPLM}, the UE selects the highest priority network available in this list. If the mobile terminal cannot connect to any HPLMN, it camps on a Visited PLMN, and periodically search for higher priority PLMN, according to the interval of time contained in the EF_{HPPLMN}.

2.2 Femtocell Technologies

The Femtocell, also known as Femto Access Point (FAP), or Home Node B (HNB), as defined by the 3GPP, provides connectivity between mobile terminals and an internet router. Backhaul connection is established via DSL or cable through an IPsec tunnel. The traffic from the FAPs is gathered by the Femtocell Gateway, which can manage between 100,000 and 300,000 Femtocells. It acts like a Radio Network Controller.

There exist two main access control strategies. In Open Access Mode the HNB can be used by any user trying to camp on it. It is the best way to increase one operator's network capacity and coverage.

Exclusive or Closed Access Mode is the most used access strategy when referring to Femtocells. Only the members of a specific Closed Subscriber Group (CSG) are allowed to camp on the associated FAP, while the others are rejected. The HNB stores the IMSI ID of the mobile terminals belonging to its allowed CSG list. User's USIM, in turn, stores in some Elementary Files the IDs of the Femtocells which the UE is allowed to camp on.

2.3 Frequencies

Mobile phones currently on the market adopt the W-CDMA technology or its HSDPA and HSUPA evolutions, all of them based on Frequency Division Duplex

(FDD). UMTS-FDD is designed to operate in many different frequency bands, the most used of them are reported in Tab.1.

Frequency bands for UMTS-TDD technology have been standardized too, but its deployment is still limited.

Table 1. UMTS-FDD frequency bands

Operating Band	Frequency Band	UL Frequencies [MHz]	DL Frequencies [MHz]	Region
I	2100	1920 – 1980	2110 – 2170	Europe, Asia, Oceania, Brasil
II	1900	1850 – 1910	1930 – 1990	North America, Latin America
IV	1700	1710 – 1755	2110 – 2155	USA, Canada

Table 2. DECT frequency bands

Frequency band [MHz]	Region
1880 – 1900	Europe
1920 –1930	USA

Tab.2 shows the frequency bands reserved for DECT technology. Because European band partially overlaps with UMTS band II, in USA Unlicensed PCS 1920 – 1930 MHz frequency band is used.

3 UMTS Services over DECT Frequency Bands

From the previous sectin, it can be observed that the European 1880 – 1900 MHz and American 1920 – 1930 MHz unlicensed bands can be used for short-range voice communications, like the ones that can be established between a Femtocell and a mobile phone. Additionally, it should be noted that to enable the use of the same device orldwide, the current mobile terminals support multiple bands are able to switch automatically from one band to another in a complete transparent way for the user. This leads to the idea that in these countries a home network could be set up without any license cost if both FAP and mobile terminal could work in the DECT frequency band. In this scenario, current mobile phones supporting a variety of frequency bands may even be directly employed with only limited changes.

Indeed, as stated in Section 2.3 and illustrated in Fig.1, the 1880 – 1900 MHz band partially overlaps with UMTS band II Uplink frequencies, while 1920 – 1930 MHz band partially overlaps with UMTS band I Uplink frequencies. Hence, current multiband mobile terminals can already work on these bands without any changes, at least for the Uplink part. The same happens for Femtocells, designed to work in different frequency bands according to the country they are destined for. A simple home network could be deployed on unlicensed spectrum using a HNB[2], which is then designated as Home PLMN. In this way, anytime the mobile terminal is outside its Femto network, it camps on a Visited PLMN, and performs a periodic search of its HPLMN, exactly as described in Section 2.1.

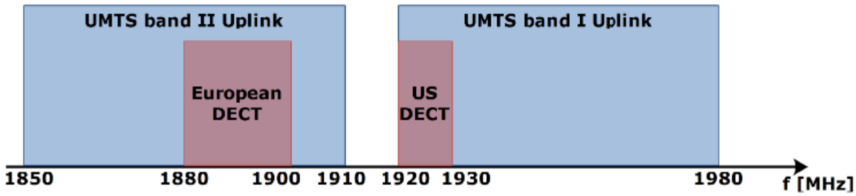

Fig. 1. Overlapping UMTS and DECT frequency bands

The problem of this solution is the Downlink part: none of the UMTS Downlink frequency bands standardized by the 3GPP include the 1880 – 1900 MHz or the 1920 – 1930 MHz bands. Additionally, transceiver's filters are designed not to allow the reception of signals outside the standardized frequency bands, as they are considered interfering signals. Therefore, existing handsets could not receive UMTS signals on DECT frequency bands over the one of the expected downlink bands. Moreover, existing Femtocells cannot transmit over these frequencies.

Considerations are to be made for the logical layer too: as described in Section 2.1, the IE Frequency Info defines what channels the terminal should use. Indeed, none of the Downlink UARFCN values correspond to a frequency in the DECT range, so it would not be possible to communicate to a mobile phone to use one of those frequencies as Downlink carrier frequency.

Finally, the only way to deploy a UMTS home network at DECT frequencies is to make some changes on both physical part and firmware of mobile terminals and FAPs. Obviously, as reported in Tab.3 changes involve supplementary costs for devices production. It might be thought that it is not worth the effort to modify handsets and, particularly, Femtocells which are more expensive[3] and less common, and thus costs would not be easily amortized. As it will be explained later on, physical changes to be made are quite limited, and components to be used are extremely cheap when compared to the cost of the devices. Besides, mobile terminal producers should not develop a specific device that can be used only in the described scenario, but they should adjust existing terminal models just adding a new working band. In this way, the price of these devices introduced

[2] HNB designed to work in US countries should be used in Europe and vice versa.
[3] Femtocells cost about a hundred dollars.

in the market could be kept in line with the existing ones. Furthermore, it should be considered that the deployment of Femtocell networks introduces considerable advantages, in addition to those cited in Section 1: thanks to the short distance between mobile terminal and FAP, and the reduced number of users the FAP has to serve, high bit rates can be achieved; short range communications implies the reduction of the power emitted, and thus the increase of the battery life, as well as the reduction of the electromagnetic pollution; Fixed-Mobile Convergence could lead to the introduction of privileged tariff plans, and the development of new specific services.

The proposed solution then requires the introduction of some changes in the physical layer of both handsets and femtocell, as well as some modification in the frequency management logic. These are aimed at the introduction of a new UMTS band in the DECT spectrum, with separate Uplink and Downlink frequencies.

The changes to be introduced in the physical layer are instead in the following two subsections.

Table 3. Disadvantages and advantages of the use of DECT frequencies for UMTS services

Disadvantages	Advantages
Changes to be made on devices physical and logical layer	Inexpensive changes
A new working band should be added to the mobile terminal	Mobile terminals would be able to work on standardized bands just like the existing ones
FAPs are still expensive	FAPs allows to improve indoor coverage
	High bit rates
	Low power emissions
	Fixed Mobile Convergence

3.1 Handset Changes

As to the physical layer, both superheterodyne and homodyne UMTS transceivers, capable to work on the Uplink frequency band of interest, have been studied. In both cases, signal is first amplified and then filtered. Considering to divide DECT bandwidth between Uplink and Downlink, their narrow bands could interfere to each other. Even though users camped on the Femtocell are supposed not to be many, interference could be enough to jeopardize reception signals. Solutions to that could be keeping Uplink channel as far as possible from Downlink channel, and using filters with cut-off frequency near to the beginning of the opposite channel, so that undesired components can be filtered without cutting off the useful signal.

The superheterodyne receiver is characterized by a RF down-converter based on a PLL, which converts the signal to intermediate frequency (IF), making it easier to be processed afterwards. The signal is then filtered by an IF filter, amplified and finally down-converted to base-band using a mixer controlled by an IF oscillator. The signal takes an analogous transmission path, opposite way. Because down-converter's output signal frequency is the absolute value of the difference between the input signal frequency and the oscillator frequency, changing input signal frequency implies changing RF or IF oscillator frequency; even other components should be changed, such as the IF filters.

In the homodyne receiver, the most used nowadays thanks to its cheapness, the signal is down-converted by a mixer based on a programmable fractional-N frequency synthesizer: through programmable divisor, synthesizer's output signal can be varied by adjusting software parameters. Within the transceiver there is a RAM that allows to store registered settings, so that they can be restored whenever the transceiver is turned on again. It is evident that it is much easier, in this case, to change the oscillator frequency, having to work just on the software.

Whatever transceiver is used, to add the DECT frequency band to those already supported by the handset, it is necessary to add a transmission and a reception physical path.

The last thing to do is to find new Downlink UARFCN values for every channel that is supposed to be appointed, and conveniently configure their correspondence in the mobile terminal.

Described changes have been summarized in Tab.4.

Table 4. Changes to be made on superheterodyne and homodyne transceivers

	Superheterodyne	**Homodyne**
Common changes	An additional transmission and reception path has to be added. Both paths need a filter with cut-off frequency near to the beginning of the opposite channel, and an amplifier. Transceivers which can work on UMTS band II for European DECT frequency band and on UMTS band I for US DECT frequency band have been considered New Downlink UARFCN values corresponding to the same number of new Downlink working frequencies have to be configured on the mobile terminal's logical layer	
Transmission path	RF oscillator working frequency bandwidth can be decreased from 60 MHz to 10 MHz or 5 MHz	Since the transceiver can work already on the Uplink frequency band, no changes have to be made
Reception path	RF or IF oscillator frequency has to be changed IF filter center frequency has to be changed	Fractional-N frequency synthesizer has to be programmed to work on one or more new frequencies

3.2 Femtocell Changes

Like the handset, even the Femtocell has to be physically changed in order to make it work on the desired frequency band. The critical part is the Downlink path again: while the demodulation is not much different from the one that is performed for a UMTS band I or II signal, the modulation has to be adjusted. Once again, particular care has to be taken in designing filters.

The new downlink UARFCN value has to be associated with the transmitted signal frequency. Because that FAP is, in fact, a Node B, it has to broadcast Information Elements contained in System Information Blocks, as described in Section 2.1. Frequency Info message, that reports UARFCN values, has to be modified accordingly.

4 Performance Analysis

As it has been discussed in Section 3.1, interference between Uplink and Downlink might be a problem, given the narrowness of the DECT frequency band, which doesn't allow for separating the uplink and downlink transmissions as it is done in the current UMTS bands. Additionally, while spatial diversity can be easily improved in the Femtocell, it it not true for the handset, given the requirement to be small.

To estimate how much the interference jeopardize the service quality, we have performed extensive simulations making use of the MATLAB and Simulink tools, as described in the following subsections.

4.1 Simulations Setup

We started with the available Simulink model of the "WCDMA End-To-End Physical Layer", which simulates a Downlink base-band transmission through an AWGN channel. We then added a Modulator block within the Wcdma BS Tx Antenna block, to up-convert the signal to radio frequencies. In-phase and quadrature components are first split, then multiplied by a cosinusoidal and a sinusoidal wave of convenient frequency, respectively. Finally, they are summed and sent through the channel.

The statistics which best characterize indoor environment are the Rician ones. Thus, the AWGN Channel block has been replaced by a Multipath Rician Fading Channel block. Multipath Rician Fading Channel block's parameters have been chosen considering that, according to radio channel measurements, K-factor ranges from 2 to 7 dB [10], Doppler shift is negligible because of the absence of rapid motions and high velocities, and delay spread does not exceed 100 ns [11]. Recall that the K-factor represents the ratio of the line of sight component signal power to the power of the multipath component.

Right before the Wcdma UE Rx Antenna block, an Uplink signal has been added. It has been chosen to place the block that represents a second UE

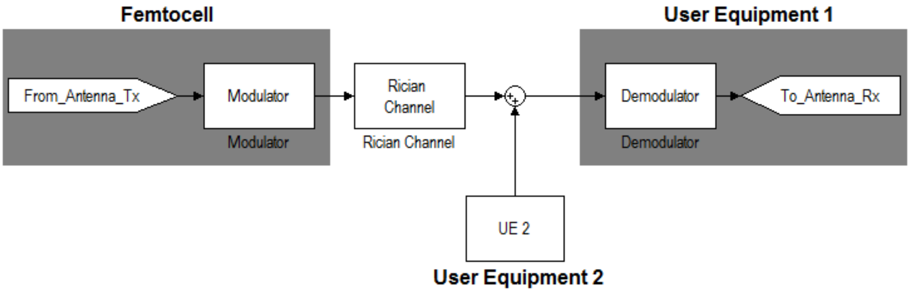

Fig. 2. Diagram of the main blocks introduced in the simulation model

after the channel, considering the worst case, and supposing to have an Uplink transmission next to the receiving UE.

Finally, a Demodulator block has been added within the Wcdma UE Rx Antenna block. To extract in-phase and quadrature components, it has been necessary to take imaginary components, introduced by the Rician channel. The two signals, up-converted by the multiplication by the sinusoidal wave in Modulator block, are then down-converted and summed as a complex signals.

The block diagram in Fig.2 shows the introduced blocks only.

4.2 Performance Evaluation

Fig.3 shows simulation results in terms of BER when the K-factor is equal to 6 dB and the European DECT band is used. We consider a reference downlink signal at frequency 1892.5 MHz and the interfering uplink signal at either 1882.5 MHz or 1887.5 MHz frequency. BER results in absence of interfering signal are also plotted, in order to allow for appropriate comparison. It can be noticed that when the carrier frequencies are 10 MHz distant, BER is not much higher than the case of absent (or quite distant) interfering signal. On the other hand, when interfering signal carrier frequency equals 1887.5 MHz, the reference signal could be completely corrupted by noise.

Fig.4 reports simulation results when K-factor equals 2 dB, which means that line-of-sight component of the useful signal is not much stronger then the reflected ones.

Results when Doppler shift is not negligible have not been reported because it would not be the typical case for indoor environments, but, as it is predictable, BER becomes quickly high when Doppler shift increases.

Reported results have been obtained using a receiving filter with cut-off frequency of 1882.5 MHz. Increasing receiving filter cut-off frequency to 1890 MHz, BER slightly decreases, as showed on Fig.5.

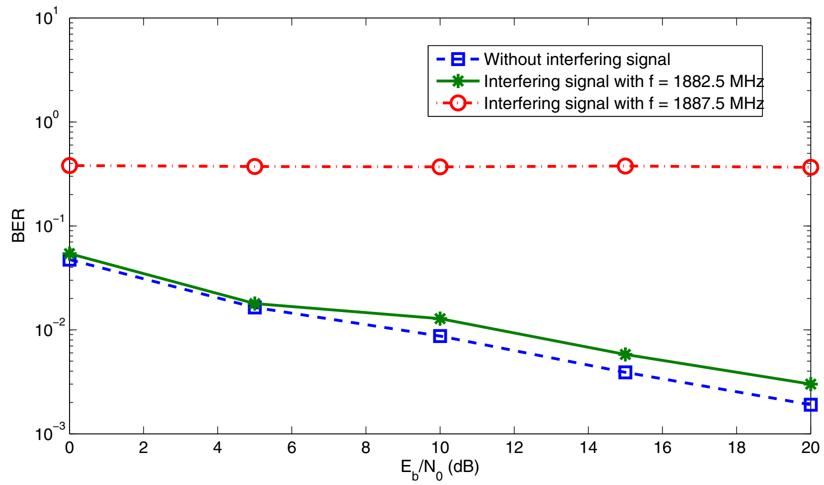

Fig. 3. BER vs E_B/N_0 with K = 6 dB and receiving filter cut-off frequency f = 1882.5 MHz

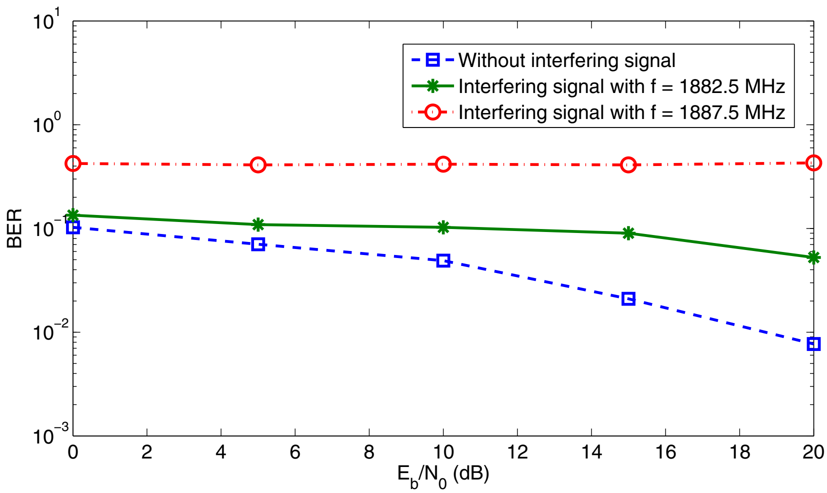

Fig. 4. BER vs E_B/N_0 with K = 2 dB and receiving filter cut-off frequency f = 1882.5 MHz

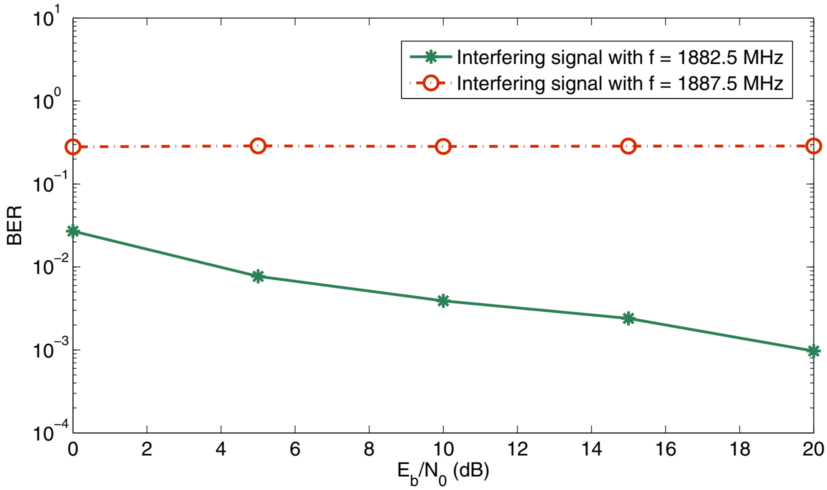

Fig. 5. BER vs E_B/N_0 with K = 6 dB and receiving filter cut-off frequency f = 1890 MHz

5 Conclusions

According to simulation results, it should be possible to deploy a UMTS home network based on a Femtocell, on European DECT frequencies. Uplink frequencies should be from 1880 MHz to 1890 MHz, while Downlink should range from 1890 MHz to 1900 MHz. Both of them could be designed to have two channels each. However, it should be considered that increasing the number of users camped on the same Femtocell increases interferences, so the same FAP could serve only a restricted number of users.

The same conclusions can't be drawn in American DECT frequencies case: Uplink frequency band should be 1920 – 1925 MHz, while Downlink frequency band should be 1925 – 1930 MHz, which means that Uplink and Downlink carrier frequency should be 5 MHz distant. As presented in Section 4.2, even using a receiving filter with cut off frequency next to 1925 MHz, Uplink signal could affect Downlink signal: considering that a mobile terminal transmits and receives at the same time, even the signal transmitted from the terminal, that is a strong signal, could jeopardize the decoding of the Downlink signal.

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